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DIRECTORATE OF CHEMICAL DEFENCE RESEARCH AND DEVELOPMENT

CHEMICAL DEFENCE EXPERIMENTAL ESTABLISHMENT

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SEA TRIALS OF THE AREA SMOKE SCREENING EQUIPMENT (CSAM)

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C.J.M. AANENSEN

PORTON TECHNICAL PAPER No. 379

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Porton Technical Paper No. 379

Copy No: 75

Date 19 OCT 1953

Sea Trials
of the
Area Smoke Screening Equipment (CSAM).

by

C.J.M. Aanensen

SUMMARY

Fourteen smoke screens using the Area Smoke Screen Equipment are described. Under standard conditions and an output of 100 lb./min., the screening length is shown to be 8,000 yds. as seen from the air and of the order of 35,000 yds. as seen from the flank. The increase in vertical screening length is shown to be roughly proportional to output.

(Sgd.) C.J.M. Aanensen,
Head, Meteorology Section.

(Sgd.) E.A. Perren,
Supt., Research Division.

CJMA/PLF.

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INTRODUCTION

The Area Smoke Screening Equipment (A.S.S. Equipment) has been designed in response to an Admiralty request for the production of large area smoke screens at sea. The equipment is capable of output up to 400 lb./min. of chlorosulphonic acid mixture (CSAM), though it does not necessarily always operate at maximum output. A pilot model had been tested on Porton ranges, and the results indicated that the screening lengths obtainable with full output would be of the order of 10,000 yards (P.T.P. 235). Since such long screens could not be satisfactorily observed on land, and the requirement was for use at sea, it was decided to test the full output at sea.

Although the primary requirement was for area screening, so that the smoke had to be observed from the air, it was decided also to observe, as far as was practicable, how it screened horizontally. Visual and photographic measurements were therefore made both from overhead and from the flank. The flank observations required a land background, and the trials were sited off the Isle of Wight whose S.E. or S.W. coast was to form the background. The choice was largely determined by the further requirement that the wind should be neither onshore nor offshore but should blow as nearly as possible parallel to the coast. In general the smoke screens were laid a few miles off-shore.

The trials were done in two series. In the first series, in the summer of 1951, the weather proved to be particularly favourable for long screens, the air on occasion being stable at no great height even when unstable near the sea surface. Trials in less favourable conditions, with thoroughly unstable air, were needed to complete the picture, and in view of the normal seasonal maximum of instability off-shore in autumn and winter a second series of trials was planned for late in the year. This series was carried out in December 1952. (An attempt was made to carry out trials in the spring of 1952, but the required conditions did not occur on the days available).

Trial arrangements

The A.S.S. Equipment was mounted on deck in the stern of M.L.6115 in the 1951 trials (Fig.2), and of H.M.S. Bern in the 1952 trials.

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While the CSAM was being drawn from a large tank it was possible to replenish the tank to some extent from drums so as to increase the time of emission, and the following maximum emission times were anticipated.

100 lb./min. for 60 minutes
200 " " " 50 "
300 " " " 35 "
400 " " " 20 "

In practice, however, owing to the rolling of the vessel these were not always achieved. On one of the 1951 trials the reservoir had to be primed by air pressure after air-lock had occurred. Between all emissions the tank had to be refilled, which could only be done on the site in the M.L. if the sea was smooth, while weight limitations precluded taking enough CSAM for more than two full-period emissions and necessitated return to harbour each night. This, of course, together with the shortness of daylight in the 1952 trials, restricted the time of day in which any trials could be done.

Throughout each emission, as far as possible, the CSAM output was kept constant and the vessel was headed nearly into the wind, moving ahead as slowly as was consistent with keeping the stern clear of the sprayed acid smoke composition.

Horizontal measurements of each smoke screen were made by a meteorological officer from C.D.E.E., Porton, on board a ship 2 - 4 miles to seaward. The "marking" ship was H.M.S. Fleetwood in the 1951 trials and in two of the 1952 trials; H.M.S. Boxer and H.M.S. Launceston Castle took turns as marking ships in the other 1952 trials. At the start of each emission the marking ship was positioned not only farther to seaward, but also several miles further downwind than the smoke source. This ship's subsequent movements were governed by the observer's requirements, but in general a distance of 2 - 4 miles from the screen was maintained, i.e., movements were more or less along wind. This distance compromised between being too far away from land to distinguish the background and being so close as to view too much of the screen obliquely. The ideal position along wind was that from which the part of the screen seen at right angles was the part where the background just showed, i.e., the effective end of the screen. The marking ship's initial position was an estimation of this ideal position and in practice had to be adjusted according to the observed behaviour of the smoke. When the screens were very long, as in most of the trials, the marking ship had to steam downwind at full speed in an attempt to reach a position abreast the effective end of the screen in time to take observations (i.e. before the screen dispersed). Unfortunately the speeds and distances required on most such occasions proved to be prohibitive so that only a lower limit to the probable lengths of the long screens could be stated. With shorter screens, as in some of the 1952 trials, however, a position approximately abreast of the average end of the effective screen was successfully reached in time for a series of half-minute measurements of angular screening length to be made with a sextant or from true bearings, the bearing of the source being known also. "Windows" in the screen up-wind, were difficult to observe from the marking ship because of oblique viewing, and were neglected if judged not to exceed ten per cent of the screen. The necessity to view them sometimes very obliquely has led to a little uncertainty here but is not considered materially to affect the figures presented in this report. Oblique viewing of the end of the screen was largely allowed for by use of the conventional $D \sin \theta$ formula.

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Angular heights of the screens were determined where possible by sextant from the marking ship, being converted to true heights by reference to the ship's track charts and the estimated wind direction as a guide in locating the smoke on a map. Errors in this conversion, however, may have been as large as 50 per cent in some of the 1952 trials, being sensitive to errors not only in the track charts but also in the estimated direction of smoke travel.

Vertical observations were made from an Anson aircraft which flew repeatedly up and down wind over each screen at whatever height gave the observer the most satisfactory view, the height being generally between 4000 and 8000 feet. Fortunately there were few low clouds on the days of the trials. The observer (another meteorological officer from C.D.E.E.) noted visually the effective length and appearance of the screen from above, while photographs were taken on each downwind run for assembly in mosaic form. Vertical screening length was determined in terms of the aircraft's ground speed and the time at which the effective end of the screen was seen passing below, and the photographs were measured in terms of the aircraft's height and the focal length of the camera. Allowance was duly made for the downwind drift of the smoke in the interval between each two pictures when they had been matched together in the mosaic.

In the 1952 trials the aircraft was also used for measurements of vertical air temperature structure over the trials site, as the 1951 trials had revealed that this important factor could no longer adequately be inferred from the temperatures measured near sea level. The temperature structure between 50 feet and 2000/4000 feet was explored on completion of the first smoke screen on each day concerned, and was taken to apply to both of the screens for that day. The Meteorological Office radio-sonde reports from Canborne and Larkhill were also consulted as a guide to the wind velocities at various heights.

The task of target vessel and smoke screen probe was carried out by H.M.S. Boxer in the 1951 trials and by H.M.S. Launceston Castle in most of the 1952 trials. During each emission the target vessel zigzagged downwind through the screen beyond about one mile from source, in order to locate the screen's approximate limits and hence find its width at various ranges as well as to note visibility inside the smoke. On several runs, too, the ship returned zigzagging upwind.

The relative positions of the three vessels were determined by radar, and the positions of at least one ship were also determined visually or by Decca. All these 'fixes' were recorded every two minutes during each smoke run and were combined in the form of track charts. Those of the 1952 trials were mutually consistent to within about a mile. In the 1951 trials the M.L. was particularly hard to locate by radar at long range, though the later use of a radar reflector proved helpful.

The 1951 trials were conducted from H.M.S. Boxer, and the 1952 trials from the marking vessel. The 1952 arrangement was better, as the marking ship remains clear of the smoke and keeps (if possible) abreast the effective end of the screen. She is thus in a much better position than the target ship to decide when each run should be terminated and what initial positions should be assumed for the next run.

(Besides the M.L. and Anson aircraft the services of H.M.S. Redpole and H.M.S. Finisterre were provided at the attempted trials in the spring of 1952).

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Weather requirements and measurements

It has become the practice to standardise smoke screen measurements in terms of certain meteorological conditions, which for the trials under consideration would be zero potential temperature gradient, a wind of 10 knots, air temperature 50°F, and with relative humidity 85%. Of these factors the temperature gradient (which in the air near the sea surface is largely reflected by the air-sea temperature difference) is undoubtedly the most important, and it was hoped that some of the emissions at least would take place in air with approximately zero potential temperature gradient. This condition occurs fairly often in summer, but it chanced to be absent on the days which had been scheduled for the 1951 trials, when inversions persisted instead. In the 1952 (winter) trials, however, besides more inversions and some marked lapses of potential temperature there were two cases of nearly zero gradient, though none of exactly zero gradient. In the 1951 trials the smoke screens were so large as to rise into air whose vertical temperature gradient was evidently not necessarily that near the sea surface, so that the air-sea temperature differences could no longer be taken as an adequate measure. Although the true gradients could not be determined then, they were fairly well inferred both from the way the smoke spread and from the radio-sonde reports in the south of England. The Anson aircraft, however, was subsequently equipped with a Meteorological Office type of aircraft thermometer by means of which, in conjunction with the readings of a sensitive altimeter at each of several levels, the relevant temperature structures at the 1952 trials were determined.

Measurements of air and sea temperatures and of air humidity and wind speed and direction were made from the smoke emitting vessel, the values tabulated in this report being the means for each emission. Sea temperature measurements which were also made from H.M.S. Boxer in the 1951 trials revealed no significant local variations in the trials area such as might possibly have been set up by tidal currents.

Apart from two emissions, no trials were attempted in 1952 with air appreciably warmer than the sea, since enough information under such favourable conditions had been obtained in 1951. Occasions of low humidity were to be used for trying out a water spray in the A.S.S. Equipment. It was hoped to compare emissions with and without the spray. One occasion appeared suitable, but in fact the general conditions for making smoke were adverse and no attempt to assess the effect of the spray can be made.

Wind directions within about 45 degrees of the N - S line were ruled out, largely because the smoke would then run too obliquely against the shore back-ground. The only important restriction on the speed of the wind was that it should not make the sea too rough for the A.S.S. Equipment to be operated. This precluded a number of trials in 1952, but two emissions were achieved in a 24-knot breeze.

Emission and weather data.

The functioning report on the equipment during the trials is embodied in Table 1. The emissions are numbered in a continuous series although the trials were carried out in two separate periods. Emission 2 (in 1951) suffered from air-lock and uneven output, the cause being surging due to a rough sea. In emission 9 (in 1952) a spray nozzle blew out, but the change to another bank of nozzles was made without interrupting the screen. This emission ended with

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failure of the diaphragm in the air blow-down valve. A second emission on 12th December, 1952, which ceased after ten minutes owing to failure of the diesel oil supply to the electrical generator and for which no useful measurements of the screen were possible, is not included in the data surveyed here. Emissions 11 and 12 were on rough sea, so that the acid could not be drawn steadily from the storage container for the full period.

Table 2 summarises the meteorological data. The vertical temperature gradients specified in the last column are those of the lowest few thousand feet of the atmosphere as they affected the smoke as a whole. Those in 1951 were broadly inferred though not actually measured. Those in 1952 were measured and are represented also in Fig.1, in which pecked lines marked Dry Adiabatic show the slope of zero potential temperature gradient on the height-temperature plot.

Descriptions of the smoke screens

Emission No.1 (1951 series).

This emission took place in conditions of slight lapse near the sea and under a partly cloudy sky. From the flank the screen formed well and was effective to over 20,000 yards (exact measurement could not be obtained). From the air the screen appeared generally good, though a few holes appeared from time to time. The width of most of the screen was estimated visually to be about 300 yards. H.M.S. Boxer found the width to be 300 - 400 yards at 5,500 - 14,000 yards from the source, the overhead being generally effective. Visually, the air observer estimated the mean screening length to be 15,000 yds. From his photographs a length of 10,000 yd. was determined. The photographs also showed that the width increased steadily to about 300 yd. at 4,500 yd. from source and then increased only slowly to 400 yd. at about 5 miles. The screen was 600 feet high at 3,500 yd. and was approximately level thereafter. This was interpreted as evidence for a stable discontinuity in the lapse rate at that height.

Emission No.2 (1951 series).

During this emission there was a slight inversion near the sea surface and then zero potential temperature gradient to about 4,000 feet. The weather was partly cloudy. From the flank the screen was very uniform in texture, and extended to over 20,000 yd. Over much of its length the height was fairly uniform too, few windows being seen. The screening length was difficult to determine, being 20,000 yd. at one time but subsequently affected by a 3,000-yd. window about half way down. The latter effect may have been due to the irregular emission. The mean overhead screening length from the photographs was 9,500 yd. but H.M.S. Boxer reported the overhead cover quite effective at ranges as far as 23,000 yd. the screen here attaining a width of 900 yd. The width increased steadily with range, being 300 yd. at about 6,000 yd.

Emission No.3 (1951 series)

During this emission the screen was mainly in sunshine. Although slight lapse was indicated to over 6,000 ft., a change in wind direction of some magnitude occurred at about 950 ft. and increased the apparent width of the screen soon after it had formed. The smoke cloud was very cumuliiform in appearance for the first two miles, large pillars occurring and no screen forming at sea level. Beyond two miles a horizontal screen formed which H.M.S. Boxer found to be about 500 yd. wide. At times the horizontal visibility in the smoke was as low as 50 yd. at 4 miles range, but there were considerable windows in the overhead screen.

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Owing to the high rate of emission the duration was only 15 minutes, and the screening length was of course still building up when the emission stopped. Owing to a misunderstanding the air observations were not continued after the emission ended, so no screening length data are available from the air. From the flank the smoke cloud was observed as a screen to a distance of about 20 miles, when observations were abandoned. The height increased slowly as time went on, being 1,400 feet at 12,000 yd. and 2,000 feet at 25,000 yd. from the point of emission.

Emission No.4 (1951 series).

Conditions during this emission were much like those during No.3 emission. As in emission No.3 the smoke rose from the M.L. in a long undulating trail not lying upon the sea surface until reaching a distance of about 2 miles. (Fig. 3c) The end then became diffuse and formed a screen from the sea surface upwards, the flank screen being effective from this point onwards. The screen was followed as far as 20 miles from the point of emission, when observations were abandoned. From the air the shear of the wind was evident in a widening of the screen and a thinning of the southern edge. The mean screening length from overhead was judged to be about 12,000 yd. visually and 16,000 yd. photographically. The photographs showed width increasing fairly steadily to 600 yd. at about 10,000 yd. while H.M.S. Boxer's record indicated widths of about half as much again. They also showed that so far as horizontal screening was concerned the width reached a maximum of about 2,400 yd. at 26,000 yd. from source. Visibility in the smoke was generally very low, being 30 - 50 yd. at 7,000 yd. downwind of the emitting ship and only increasing to 100 - 300 yd. at 28,000 yd. The heights of most of the screen was about 1,400 feet.

Emission No.5 (1951 series).

Although the sea was warmer than the air on this occasion the instability only extended up to a small height, possibly not more than 100 feet, above which there was an inversion to about 1,000 ft. Moreover the wind veered considerably with height at about 100 ft. above sea level. Throughout the emission the smoke rose from the M.L. to some 50 - 100 ft. and then descended to sea level forming a large arch about 3,000 yd. long. (Fig. 3d). From the downwind end of this arch the flank screening appeared uniform to at least 22,000 yd., where observation was abandoned. The height of the screen was between 160 and 220 feet. H.M.S. Boxer reported that the horizontal visibility in the screen was mainly 25 to 100 yd., and the width increased from 300 yd to at 6,500 yd. to 1,000 yd. at 17,000 yd. The screen, however, was so low that the sky could often be seen overhead although the screen was effective at an oblique angle. Visually the air observer estimated the screening length at 10,000 yd., but photographically it seemed hardly to extend beyond 5,000 yd. As the screen thinned out a flocculent appearance was seen. The sky was almost cloudless.

Emission No.6 (1951 series).

The sky was cloudless, and there was slight stability near the sea but a marked change of wind direction at about 1,000 feet. The smoke formed a large arch from the M.L. to a point about 2,000 yd. downwind. Beyond this the flank screen at sea level slowly formed and became uniform. (Fig. 3e). It was observed to 28,000 yd. downwind, where observation was abandoned. Owing to the wind shear the upper part of the screen drifted quickly across the direction of the surface wind and so widened the effective overhead cover. (Fig. 4f).

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From the air photographs the width appeared to be about 800 yds. at 6,000 yd. down the screen, but it is obvious (and this was confirmed by visual observations from the aircraft and from H.M.S. Boxer) that the screening from vertical observation was not completely effective since the screen had great numbers of little holes. This structure (due, no doubt, to the wind shear and smooth air flow) caused great difficulty in estimating the effective length of the screen. Visually from the air it appeared to be no more than 9,000 yd., and this was confirmed by the photographs. The main part of the top of the screen lay between 900 feet (at 4,000 yd. from source) and 1,100 feet (at 18,000 yd.). Horizontal visibility in the screen was of the order of 100 to 500 yd. at 6,000 - 15,000 yd. from source.

Emission No.7 (1951 series).

This emission followed straight on after No.6. In general appearance and texture it was much like No.6, except for being considerably larger. Full observation of it was hampered by increase of haze and by the intrusion of natural cloud between the smoke and the air observer. It was possible, however, to estimate that from the air the screen extended to at least 17,000 yd. visually and to over 20,000 yd. photographically. It was effectually 1,000 yd. wide at 5,000 yd., and 1,600 yd. wide at 14,000 yd. In the screen H.M.S. Boxer found some irregularity in the overhead cover whilst the horizontal visibility was of the order of 300 - 500 yd. Notwithstanding being thin, the screen was effective as a flank screen for more than 26,000 yd. Its height was of the same order as from emission No.6.

Emission No.8 (in 1952)

This emission took place under clear sky in air which was stable, the inversion of potential temperature being 30°F. in the first 50 feet and altogether 70°F. in 3600 feet. The screen lay straight and low. From the air it appeared effective to about 7,000 yd., where its width was 300 yd. The width of the smoke plume was less than 700 yd. all the way to 13,000 yd. from source. Visual and photographic estimates agreed fairly well. Seen horizontally, from the flank the screen lengthened to at least 25,000 yd., with a height of 200 - 400 feet. H.M.S. Launceston Castle, in the smoke, reported horizontal visibilities of about 25, 50 and 75 yd. at respective distances 5,000, 10,000 and 15 - 20,000 yd. from source.

Emission No.9 (in 1952).

Meteorological conditions were almost as for emission No.8, and the smoke lay similarly. Screening lengths and widths, however, were greater, the widths at 5,000 and 10,000 yds. being respectively about 400 and 600 yd., both visually from the air and as reported by the target ship. Visually from the air the screen extended to about 15,000 yd. for a quarter of an hour and then shortened to 5,000 - 10,000 yd. The sea was so faint in the photographs that it was hard to interpret them, and only over a mean distance of about 9,000 yd. did they certainly show complete screening. Seen from the flank the screen was 500 - 600 feet high and was still lengthening at 34,000 yd., beyond which no land background remained available. H.M.S. Launceston Castle found visibility less than 50 yd. in the smoke as far as 8,000 yd. from source.

Emission No.10 (in 1952).

Conditions here were of slight lapse except for an isothermal layer at about 500 feet. Winds were similar to those of emissions No. 8 and 9,

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and the sky was clear up to over 5,000 feet, though some clouds kept the sunlight off the smoke and made the air photographs less clear. The lapse conditions made the screen rather uneven, but on the whole the smoke was not more than 800 yd. wide at 10,000 yd. from source as reported by the target ship. The visual screening length from the air was never more than 4,000 yd., though patches as far as 6,000 yd. were effective. Flank observation was for the first time successful in being from a point where the screening length could be repeatedly measured after reaching a "steady" state. This screening length averaged 15,000 yd. The height of the screen at this distance was roughly 1,000 feet. H.M.S. Launceston Castle, in the smoke as far as about 10,000 yd. from source, reported "poor" visibility but gave no figure lower than 200 yards.

Emission No.11 (in 1952)

Wind and lapse were both strong, the potential temperature lapse being 4°F. in the first 50 feet and 2°F. from 50 feet to 2000 feet. The sea was rough and the air was unstable and very turbulent. The sky was clear. The screen, with many windows, pillars and thin patches, was effective over a mean length of 7,000 yd. as seen from the flank. No aircraft or target ship was available, and the screen top was far too irregular for any representative measurement of height.

Emission No.12 (in 1952)

Conditions were as for the eleventh emission, but the aircraft was now available. The water spray was operated during this emission. White horses were distinct in the air photographs, but the smoke moved so much between photographs that the mosaic could not be made accurately. Moreover the aircraft carried out only three runs, the third of which was ten minutes after the end of emission when no smoke remained dense enough to screen at all. Visually from the air a mean of 3,600 yd. was reported as the screening length. The photographs showed dense patches up to 8,000 yd. but also thin patches increased considerably beyond 4,000 yd. Flank screening length averaged only 4,000 yd. Width was about 300 yd. at this distance from source, and was rapidly increasing down wind. Height was very irregular, and the smoke did not all lie upon the water.

No conclusions on the effect of the water spray could be drawn.

Emission No.13 (in 1952)

There was a 1°F. lapse in potential temperature from 50 to 2,000 feet, above which the air was stable. The lowest 50 feet were almost isothermal. The sky was clear except for some thin high clouds which, together with a very slight haze, so affected the light that the photographs showed hardly any sea detail and could not be matched reliably into a mosaic after the end of emission, which was short (20 min.) The lapse conditions gave to the smoke a typically uneven form, roughly 300 yd. wide at 3,000 - 4,000 yd. and thereafter widening rather irregularly. A screening length of over 5,000 yd. was seen from the air but the photographs show considerable variation between 3,000 and 6,000 yd. From sea level the screen was effective to at least 24,000 yd. Its height, again very uneven, was of the order of 2,000 feet. Visibilities in the smoke at 2,000 yd. and at 5 - 10,000 yd. were respectively 25 and 50 yd.

Emission No.14 (in 1952)

Conditions were as for the thirteenth emission except that the sun was low and the light was poor so that the photographic estimates of screening length are very doubtful. Visual screening length from the air was about 3,000 yd., where the width was about 200 yd. The target ship reported smoke

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widths reaching 1,000 yd. at 15,000 yd. from source, the edge of the smoke being described as very diffuse. Plank measurements, after attainment of "steady" conditions, showed a mean screening length of 16,000 yds. Screen heights was again of the order of 2,000 feet. Visibility in the smoke was as low as 25 yd. at the first few thousand yards range, increasing to 100 yd. at a range of the order of 5,000 yd.

Analysis of Results

From the experimental data obtained from many previous smoke screen emissions over the sea it is known that, for horizontal viewing of screens of the order of at most a mile or so, the results can for any apparatus be reduced by the formula.

$$L \propto Q^a u^{-b} f(R).$$

where L is the screening length, Q the rate of emission, u the wind speed, $f(R)$ depends on the temperature gradient and the indices a and b are both about 1.0 or perhaps may be slightly smaller in value. Strictly speaking the speed of the emitting ship should be taken into account as well, but in the trials discussed it was much smaller than the wind speed and can be neglected. How far this formula applies to very long screens is not known nor whether it applies to screening from the vertical. It is moreover clear that the form of $f(R)$, which accounts for the effects of the temperature gradients, must be more complicated in the case of large screens because of the greater height to which the screen rises and the consequently more complex temperature and wind structure involved in the diffusion of the smoke. The small number of trials in the present series and the difficulty of obtaining complete measurements precludes a full resolution of the reduction and analysis of results. It is however of interest to see to what extent the formula is supported or not.

In planning the trials the emissions on each day were arranged to be at different strengths, so that as far as possible the effect of varying output could be deduced from the results of each working day. Unfortunately circumstances resulted in only three such groups; emissions Nos. 6 and 7, 8 and 9, and 13 and 14. Examination of the observed screening length measurements in these cases show that they are consistent with the rule that the screening length is approximately proportional to the output, but there is insufficient evidence to make the result conclusive to the exclusion of other near relations. As this result has been indicated in other work (cf. P.R.2734) it is not likely to be far from the truth, and has been used in the reduction of the observations.

With regard to the reduction to standard wind conditions, it is not possible from the observations to determine the value of the index to be used. From previous work carried out over the sea the value can, however, be assumed to be unity provided the wind range is not unduly great and provided the air is not unstable. (Otherwise the index may depend markedly on the stability). With the exception of emissions 11 and 12 such unstable conditions were not encountered and in this case the observations form a pair for the determination of the effect of a water spray and for this they need not be reduced to standard conditions.

For comparisons of the various observations it is also necessary to allow for the direct effect of air temperature and humidity on the formation of the CSA smoke. This has been done by means of the factors given in P.R.2437.

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The reduction of the observed screening lengths to the partial standard conditions of an output of 100 lb./min., wind speed 10 knots, temperature 50°F. and relative humidity 85% has been carried out only in the case of the vertical screens and the figures obtained are given in Table 3. Except in the cases of emissions 5, 6 and 7 where the screens were obviously distorted by a wind shear at no great height, and emissions 11 and 12, which were not reduced because of the unstable conditions under which the screens were made (a water spray was used for emission 12 too), these reduced figures from a group for which mean values may be confidently deduced. (It will be noticed that this remaining group of observations contains three definitely slightly unstable conditions and two definitely stable conditions. Thus though no adjustment has been made for stability the distribution around the neutral condition is roughly equal. That the figures do not give much longer screens for the stable conditions than for the unstable ones may be either a result of the strength of wind in the inversion conditions or because a constant wind index was used). Taking the mean of this group of observations to relate approximately to neutral conditions, we obtain 8,100 yds. for the visual observations and 7,600 yds. for the photographic. The agreement between the two methods is pleasing and a round figure of 8,000 yds. can be adopted as the vertical screening length for an output of 100 lb./min. under standard conditions.

Turning now to the observations of screening from the flank, it is unfortunate that measurements of the whole screen could only be made in a relatively small number of cases. In fact only emissions 10, 11 and 14 give defined horizontal screening lengths. If we reduce these three lengths to an output of 100 lb./min. and standard conditions (except for stability) as we did for the vertical screening we get the three values given in Table 3. Emissions 10 and 11 were made in unstable air, whilst the wind and temperature structure were peculiar in emission 14. It is thought therefore that in arriving at a figure for the horizontal screen under neutral standard conditions one should take more notice of the former results. It is therefore estimated that the horizontal screening length is of the order of 35,000 yds. for an output of 100 lb./min. It is however emphasised that the figure is tentative owing to the lack of observations, difficulty of making them, and assumptions made in the reduction thereof to standard conditions.

The excess of the horizontal over the vertical determinations of screening lengths is very striking and in contrast to similar determinations for small sources over land. The reasons for this are by no means clear, but are obviously connected with different degrees of vertical and horizontal diffusion under the conditions pertaining in the trials and may also be due to some extent to the different distances of the view points and different backgrounds in the two sets of observations. The importance of the effect is obvious since presumably the screening of areas is required primarily against aerial observations and the results indicate that the source strength increase does not produce such a commensurate vertical screening length increase as would have been anticipated from previous results.

The heights of the screens are summarised in Table 3. It will be seen that in general the top of the screen appears most frequently to be dependent on the position of some stabilising layer, which was not always in evidence in the aircraft temperature soundings (or nearest radio-sonde sounding). It is difficult to understand how the top of the screen was frequently so smooth and uniform were this not the case. In so far as the effective edge of the smoke screen marks approximately where a certain integrated concentration (along the line of sight) is attained, it would be expected that an increase in the output would increase the height (and width) of a screen. The measurements made in these trials were not designed to test this, but there is some support for it, as, for example, comparisons of emission 8 and 9 show.

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In considering the widths of the screens, there are several "widths" which can be observed, viz: the width of the screen seen or photographed from the aircraft, the widths of the screen as seen from the target ship (a) as regards observations of the sky, (b) as regards flank observation. Observer's remarks concerning the latter have been given. Regarding the former, it was decided to measure and put on record the former as obtained from the photographs. Table 4 gives mean widths at downwind intervals of 2,000 yds. as obtained from mean curves through the plotted photographic observations of vertical screening widths. Such widths can be expected to show variation with atmospheric stability but this effect was hidden by the widening of the screen by the wind changing direction with height, of which emission 7 is the most notable occasion.

Summary of conclusions

1. The screening length which can be expected under standard meteorological conditions for an output of 100 lb./min. of CSAL is 8,000 yards against viewing from the air and about 35,000 yards against flank viewing. There may be a skip distance of as much as two miles in the horizontal screen in stable conditions.
2. The screening lengths appear to be approximately proportional to the output up to 400 lb./min.
3. The use of an inverse relation between vertical screening length and the wind speed is a working approximation, provided lapse conditions beyond slight are not included.
4. Temperature differences between the sea surface and the air near it are insufficient to forecast the size and shape of a smoke screen. Full information of temperature and wind structure to the height reached by the screen is necessary.
5. Screens are much longer when viewed from the flank than when viewed from above.
6. Horizontal visibilities inside the screens were very variable, sometimes being only 25 yards at ranges up to 5,000 yards from the source.

Acknowledgement

The Engineering Section, C.D.E.E., were responsible for the preparation and operation of the A.S.S. Equipment.

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CJMA/PWF.

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TABLE 1

Summary of functioning Report

Emission No.	Date	Time of start G.M.T.	Period of emission (minutes)	Acid emitted (lbs.)	Average pressure (lbs. per sq.in.)	Output rate, (lbs./min, approx.)	Remarks.
1	July, 1951 11	0810	48	5500	120	114	Surging in tank cut the emission short.
2	11	1249	(38)	-	-	(200)	Surging caused air-lock.
3	13	0817	15	5500	110	366	Surge caused pressure drop.
4	13	1021	30	5600	120	187	
5	17	0740	30	2800	125	93	
6	18	0954	30	5900	120	197	
7	18	1143	19	7500	130	395	
	Dec. 1952						
8	11	0949	60	5700	120	95	
9	11	1141	44	8360	120	190	
10	12	0925	60	5700	120	95	
11	15	1125	37 [*]	6440	120	174 [*]	Rough sea; acid pressure dropped to 50 lb./sq.in. after 26 min.
12	15	1358	24	5040	130	210	Four water sprays operated at 54 - 55 lb./sq.in.
13	18	1221	20	6500	95 to 100	325	
14	18	1413	60	5700	120	95	

* 190 lb./min. for 26 min., 125 lb./min. for 4 min., 140 lb./min. for 7 min.

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TABLE 2

Summary of Mean Meteorological Conditions during emissions.

Emission No.	Source speed up wind (knots)	Wind Speed (knots)	Air temperature at about 15 feet. °F.	Sea surface temp. °F.	Relative humidity %	Stability conditions in the lower layers of the atmosphere.
1	3.9	14.7	60.1	61.0	90	Slight lapse to 4500 ft. indicated by R/S sounding but smoke indicated stability at 600 ft.
2	-	(15)*	61.3	59.5	89	Slight inversion near sea; zero potential temp. gradient above.
3	4.5	11.7	57.7	60.0	85	Slight lapse to over 6000 feet, but wind shear at 950 feet.
4	1.5	11.8	58.2	59.0	87	ditto
5	1.9	8.7	59.6	60.4	91	Surface instability changing to inversion at about 100 feet with a wind shear.
6	2.6	8.3	61.2	60.7	93	Very slight stability below 1000 feet, with pronounced wind shear at 1000 ft.
7	2.9	8.7	60.6	60.9	96	As for emission 6 except that the wind shear appeared to be even more marked.
8	1.5	12.4**	47.0	45.8	89	Inversion; air stable to at least 4000 feet.
9	0.2	15.4	47.4	46.0	87	ditto
10	1.3	12.3	44.8	46.5	79	Slightly unstable, except for a nearly isothermal layer at about 500 feet.
11	1.8	24.8	38.7	44.3	72	Unstable to 2000 feet; slightly stable higher up.
12	0.6	24.3	40.2	44.5	65	ditto
13	0.5	17.8	43.4	44.5	67	Slightly unstable to 2000 ft., though practically isothermal at the bottom.
14	0.5	13.3	43.7	43.2	72	ditto

* Approximate; source speed unknown.

** refers to the last 20 min. only.

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TABLE 3

Screen data

Emission No. and nominal output (lb./min.)	Top of screen		Observed screening length (thousands of yards)			Screening lengths (thousands of yards) adjusted for Q = 100 lb./min., u = 10 knots 50°F. and R.H. = 85%		
	Range (thousands of yards)	Height (feet)	Horizontal (visual)	Vertical (visual)	Vertical (photographic)	Vertical (visual)	Vertical (photo.)	Horizontal (visual)
1 (100)	>3.5	600	>20	15	10	8.6	5.9	-
2 (200)	Most of screen	1200	> 20	-	9	-	-	-
3 (400)	12 25	1400 2000	>40	-	-	-	-	-
4 (200)	Most of screen	1400	>40	12	16	4.4	5.9	-
5 (100)	Most of screen	160 to 220	>22	10	5	4.2	2.1	-
6 (200)	4 18	900 1100	>28	9	9	1.4	1.4	-
7 (400)	Most of screen	900 to 1100	>26	>17	>20*	>1.4	>1.4*	-
8 (100)	5 to 25	200 to 400	>25	7.0	5.5	8.8	6.9	-
9 (200)	15 to 30	500 to 600	>34	13	9.3	10.4	7.5	-
10 (100)	12 to 15	1000	15	2.9	4.0	6.3	8.8	34
11 (200)	Most of screen	very irregu- lar.	7	-	-	-	-	35
12 (200)	Most of screen	very irregu- lar.	4	3.6	4.2	-	-	-
13 (300)	Most of screen	about 2000	>24	> 5	5*	>9	9*	-
14 (100)	Most of screen	about 2000	16	2.8	2.5*	10.1	9.2	62

* poor photographic record.

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TABLE 4Mean photographic cloud widths (in yards)

Range (yds.) Emission No.	2000	4000	6000	8000	10000
1	200	280	300	360	
2	180	240	320		
3	140	280	440	600	
4	160	310	460	560	600
5	280	360			
6	310	550	760		
7	460	780	1020	1200	1400
8	160	230	260		
9	170	270	350	420	
10	180	290			
11	-	-	-	-	-
12	140	280			
13	190	280			
14	160				
Mean*	190	300	410	480	-

* The exceptionally wide emission 7 is omitted from this mean, as being a special case due to a marked wind-shear.

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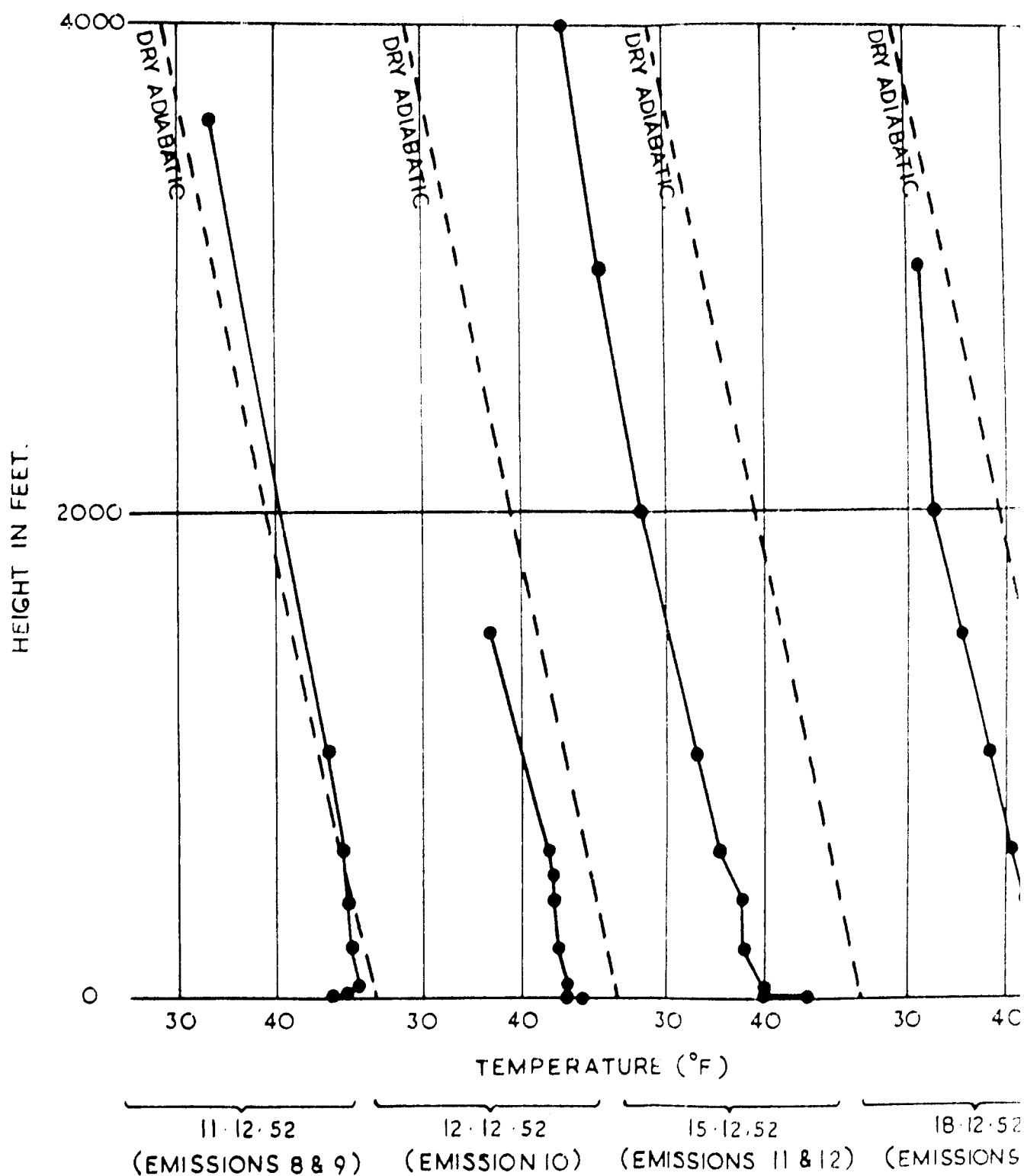


FIGURE 1. AIR TEMPERATURE STRUCTURES ON THE SITE OF THE NAVAL SMC

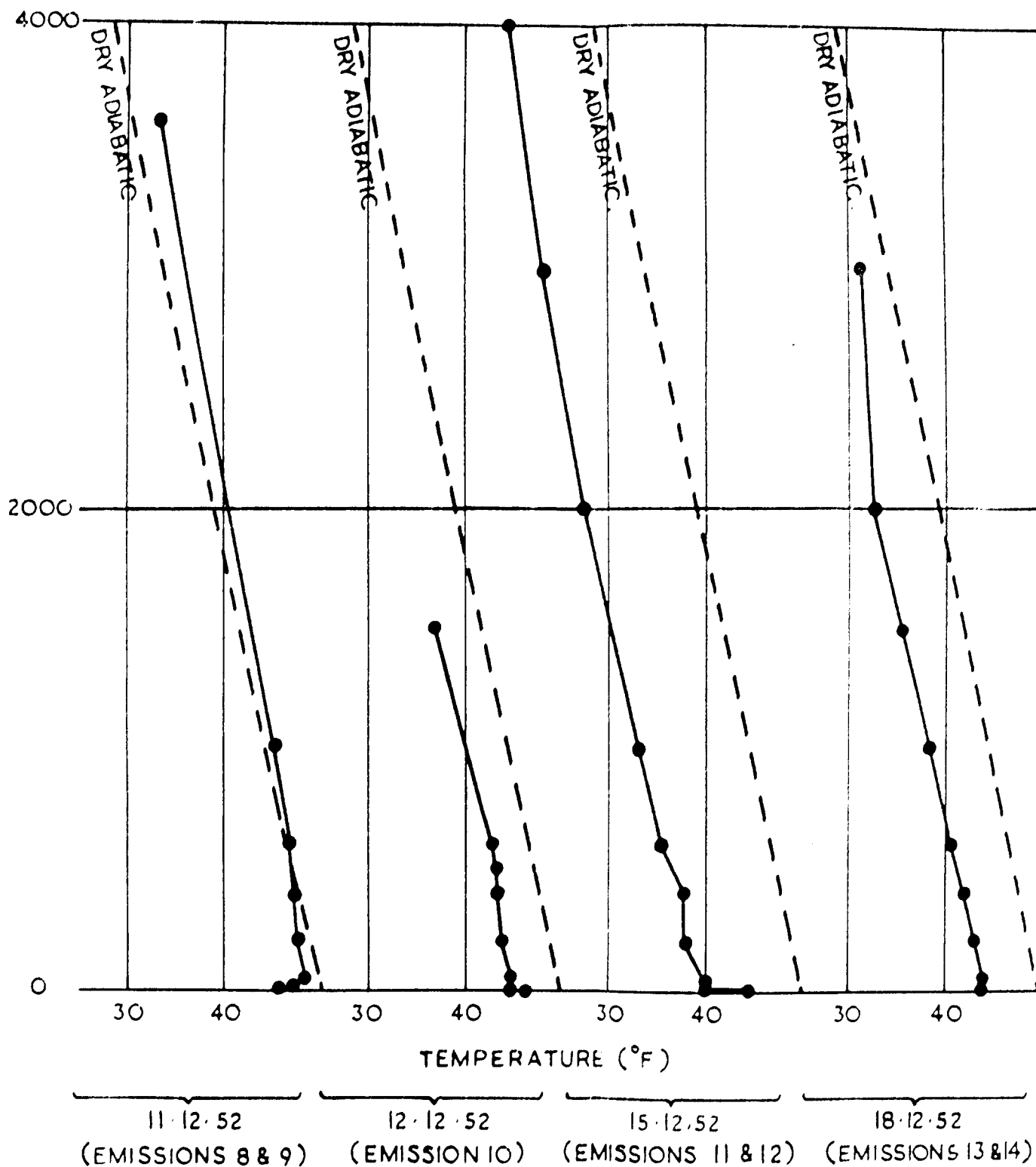


FIG. 1. AIR TEMPERATURE STRUCTURES ON THE SITE OF THE NAVAL SMOKE TRIALS (1952)

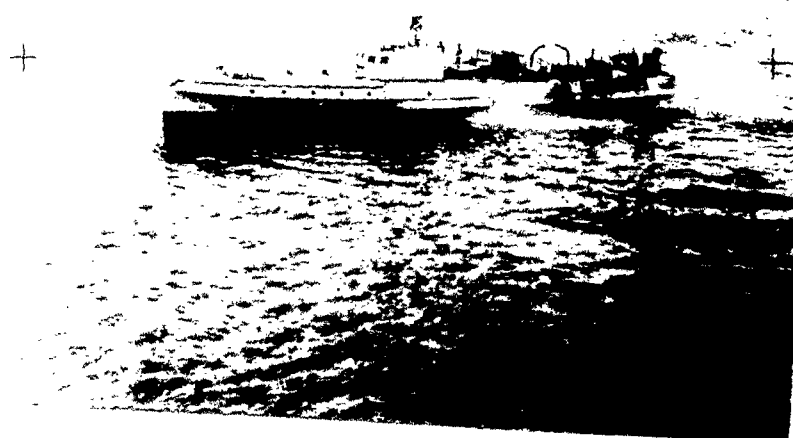


FIG 2. ML 6115 WITH THE A.S.S. EQUIPMENT INSTALLED.

T 988 | 1

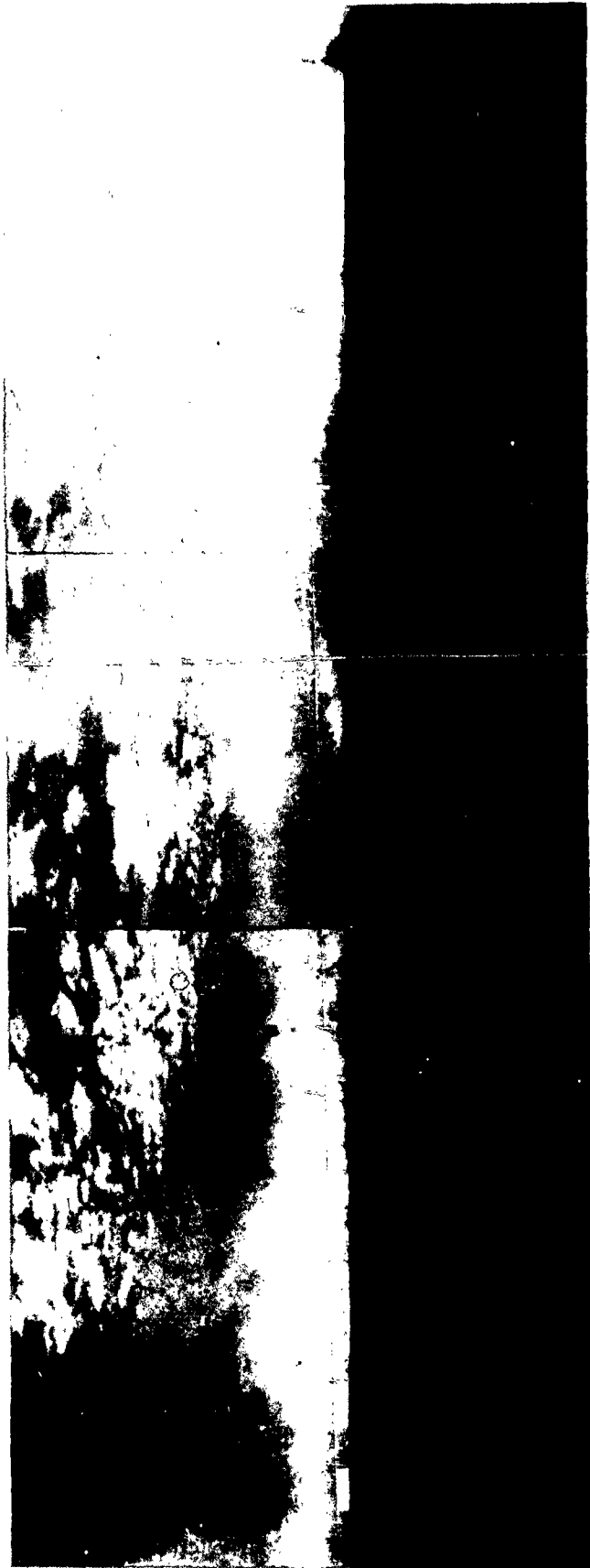


FIG 3 (a) FLANK VIEW OF EMISSION N° 1 AT Z + 16 min.
rouk

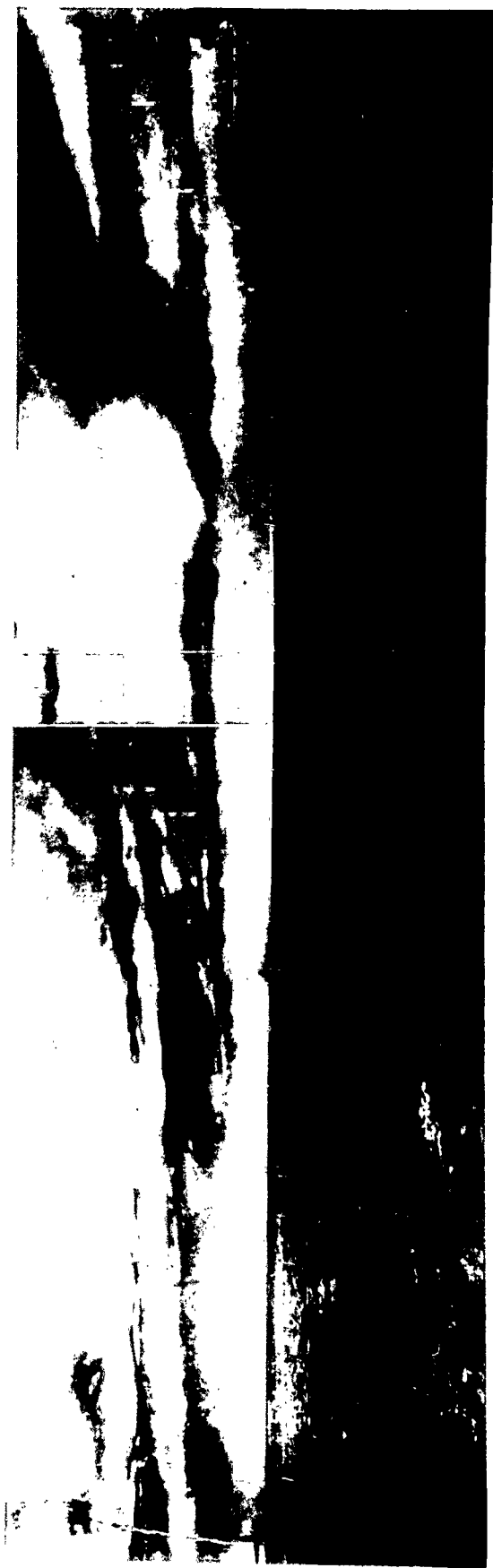


FIG. 3 (b) FLANK VIEW OF EMISSION N° 2 AT $Z + 22$ min.

FIG 3 (c) EMISSION N° 4 AT Z + 11 min SHOWING THE SERPENTINE
FORMATION OF THE SMOKE CLOUD ABOVE THE SEA SURFACE
FOR THE FIRST TWO MILES. THE USEFUL HORIZONTAL SCREEN
IS STILL EXTENDING DOWNWIND.

1980/4



FIG 3 (d) EMISSION N° 5 AT $Z + 5$ min SHOWING THE 3 000 YD. LONG
ARCH OF SMOKE FROM THE EMITTER.

1996/5.

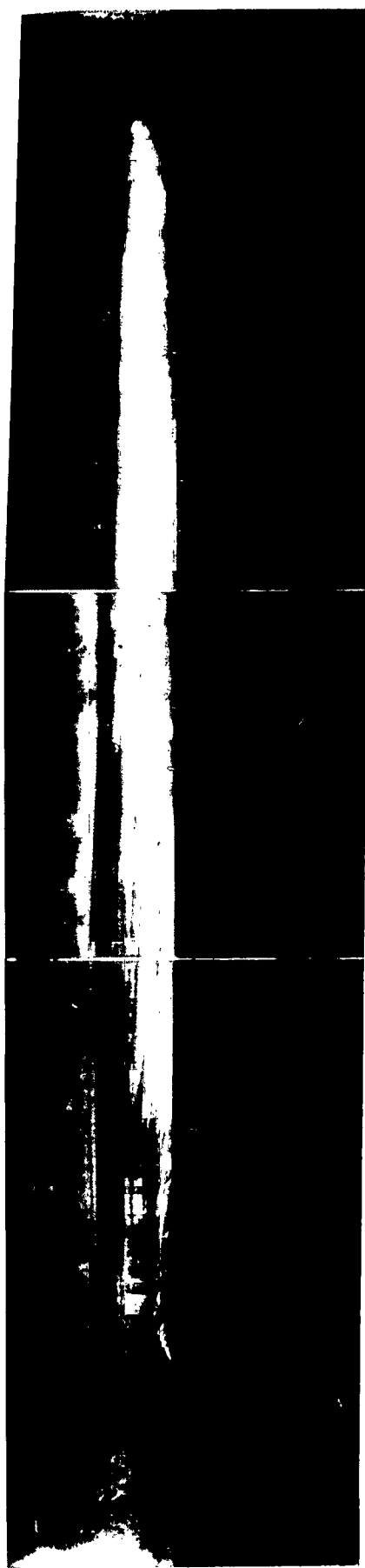


FIG 3 (c) EMISSION N° 6 AT Z+21 min SHOWING THE INITIAL SMOKE
ARCH AND THE EFFECT OF THE CHANGE IN WIND
DIRECTION AT A RELATIVELY LOW HEIGHT.

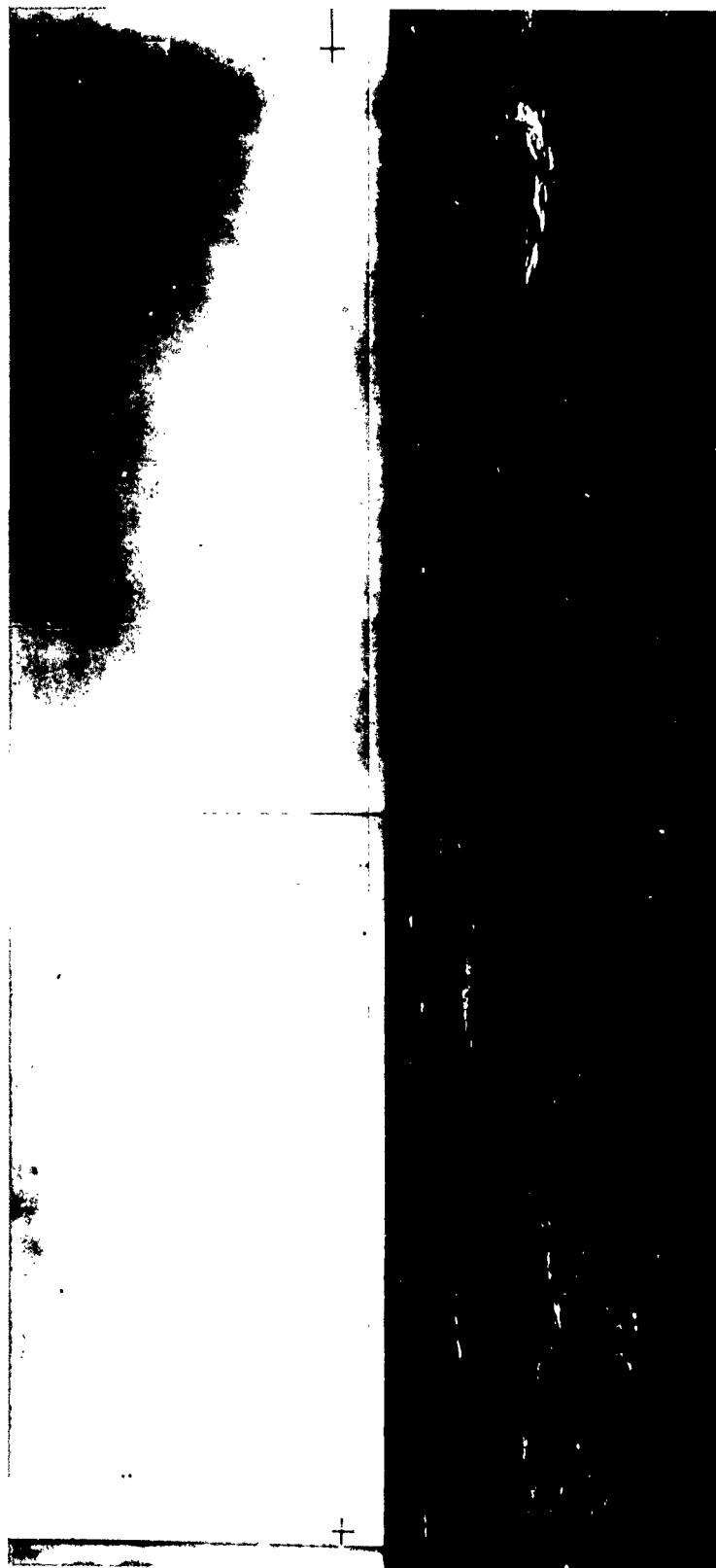


FIG. 3 (1) FLANK VIEW OF EMISSION N° 11 AT Z + 15 min. 1 088/7



FIG 3 (g) FLANK VIEW OF EMISSION N° 13 AT $Z + 15$ min.
r 988/8



FIG. 4 (a) EMISSION N° 1 AT Z + 26 min FROM 5,000 FT.

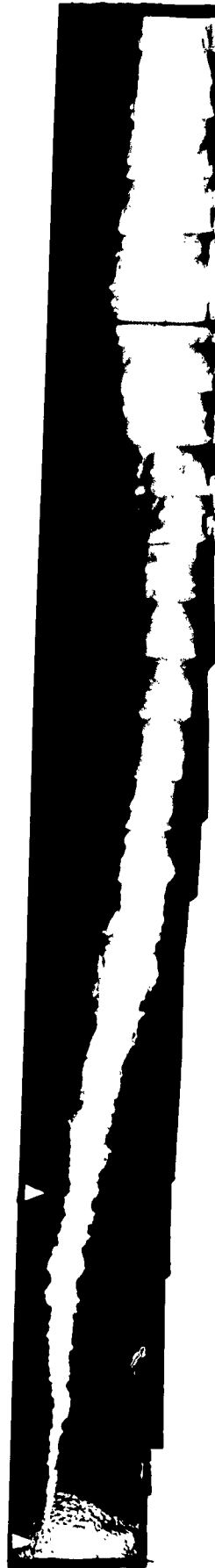


FIG 4 (b) EMISSION N° 2 AT Z + 22 min FROM 3,000 FT.

NOTE: IN THE ABOVE AND THE FOLLOWING PHOTOGRAPHS TAKEN VERTICALLY DOWNWARDS FROM THE AIRCRAFT THE DISTANCE BETWEEN THE PAIR OF POINTERS IS 2,000 YD.

100/1.



FIG. 4 (c) EMISSION N° 3 AT Z + 15 min FROM 8,000 FT.

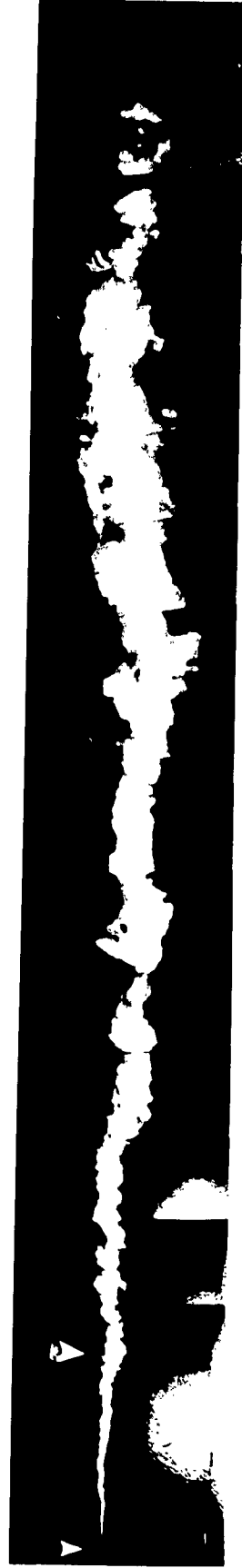


FIG. 4 (d) EMISSION N° 4 AT Z + 28 min FROM 8,000 FT.

148110

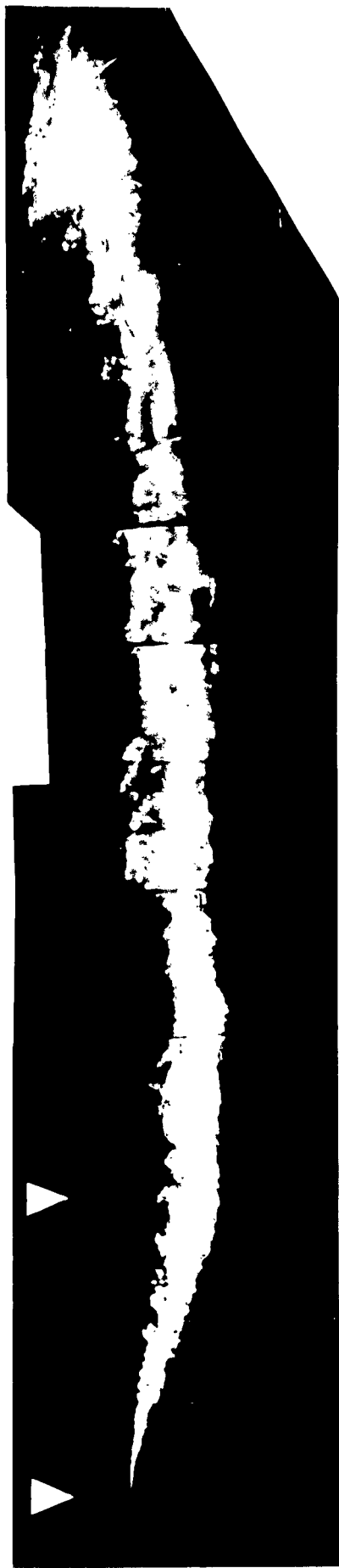


FIG. 4 (c) EMISSION N° 5 AT Z + 25 min FROM 8,000 FT.
T_{total}



FIG. 4 (1) EMISSION N° 6 AT Z + 16 min FROM 8,000 FT.
2,945/12.

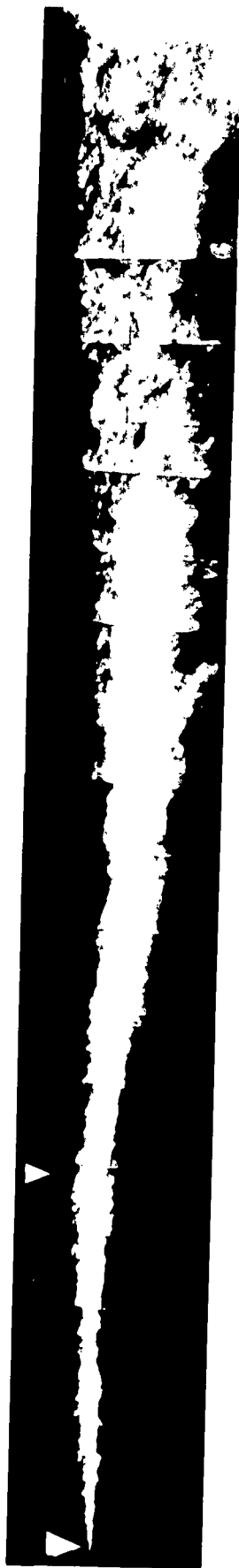


FIG. 4 (g) EMISSION N° 8 AT Z + 28 min FROM 4,000 FT.

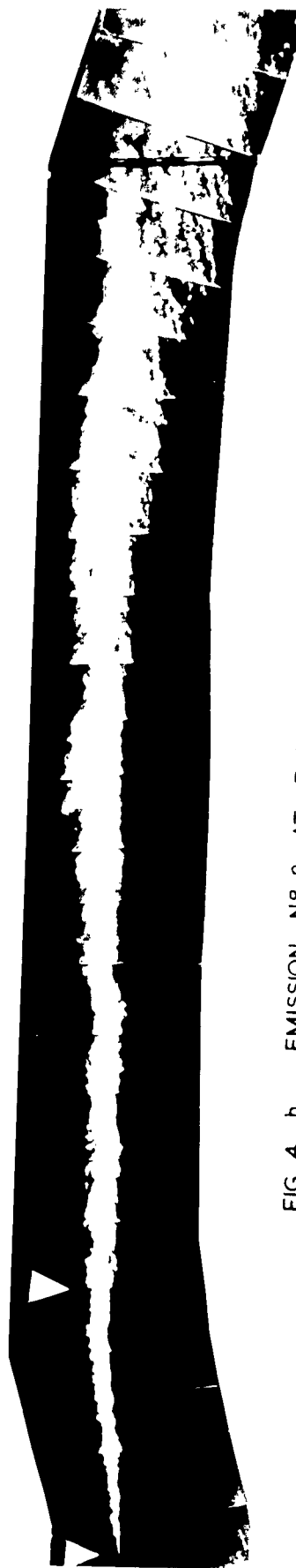


FIG 4 h EMISSION N° 9 AT Z + 27 MINUTES FROM 4 500 FT.
TASSEL



FIG 4 (i) EMISSION N° 10 AT Z + 24 min FROM 5,000 FT.

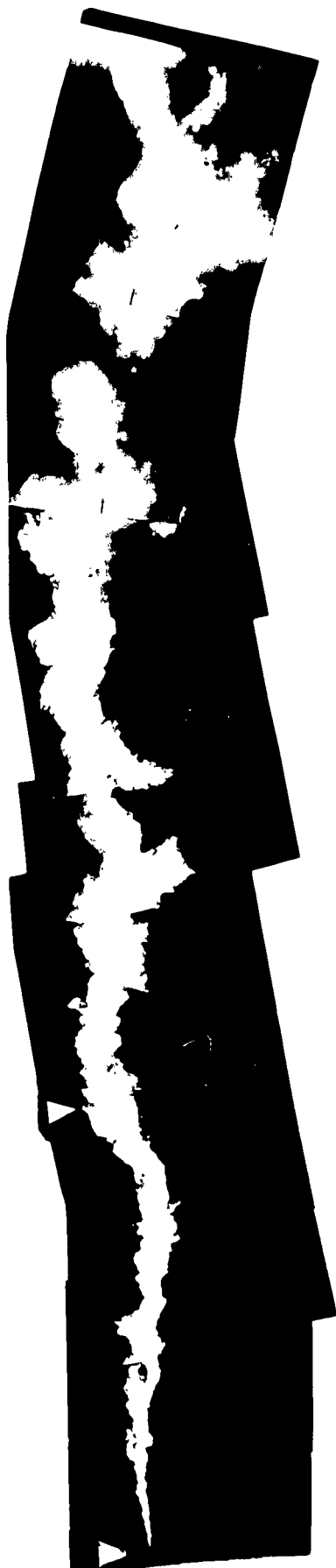


FIG. 4 (j) EMISSION N° 12 AT Z + 25 min AT 3,500 FT.



FIG 4 (k) EMISSION N° 13 AT Z + 9 min FROM 4,000 FT.



FIG 4 (L) EMISSION N° 14 AT Z + 18 min FROM 4,000 FT.

2.900/s.

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